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THE DETERMINATION OF NOCTILUCENT CLOUD PROJECTION ON THE EARTH'S SURFACE

M.A. Dirikis, Ye.Ye. Mukins

ABSTRACT. For approximate determination of geographic coordinates of noctilucent cloud projections on the earth's surface using single photographs, it is assumed that the height of the clouds is constant and equal to 82 km. A special table is compiled by means of an electronic computer for the purpose of facilitating calculations. Attempts were made to determine horizontal displacements of some details of noctilucent clouds. Various sources of errors of obtained velocities are discussed. /52*

Many years of observations conducted in Latvia have produced considerable number of photographs of noctilucent clouds. However, more than 90% of all this photographic material, for one reason or another, cannot be used for basic processing [1, 2]. Nevertheless, practically all of the material can be used for the approximate determination of the geographical coordinates of the projection of the noctilucent clouds onto the earth's surface [3]. According to the plan of the International Geophysical Year - Year of the Quiet Sun, and the corresponding instructions of the Central Council of the All-Union Astronomical and Geodetic Society, it would be desirable to process the entire lot of the single photographs particularly for this purpose [4]. We began this work in 1962.

We compiled special tables for approximate processing of the single photographs of noctilucent clouds. They give the geographic latitudes φ of the noctilucent cloud's projection and the difference of the longitudes $\Delta\lambda$ of the projection and the observation point as a function of the azimuth and altitude. The tables were compiled according to formulas:

$$\sin\varphi = \sin\varphi_0 \cos d + \cos\varphi_0 \sin d \cos A,$$

$$\sin\Delta\lambda = \frac{\sin A \sin d}{\cos\varphi},$$

* Numbers in the margin indicate pagination in foreign text.

where φ_0 is the geographical latitude of the observation point; A is the azimuth of the noctilucent cloud location point; d is the angular distance from the observation point O to the noctilucent cloud location point C (Fig. 1).

The tables have been compiled for the geographical latitude φ_0 of the Sigulda observation point of the Latvian Section of the All-Union Astronomical and Geodetic Society [5], where for the past eight years more than 1500 negatives of noctilucent clouds were obtained.

The arguments of the table were chosen in the following way:

Azimuth A from 0° to 100°, counting from the point North in both directions for reasons of symmetry, at every 0.5°; altitude from 4° to 30°, moreover from 4° to 10° at every 0.2°, and from 10° to 30° at every 0.5°. For altitudes of less than 10°, refraction was taken into consideration [3].

When compiling the table it was assumed that the Earth is spherical and that the altitude of the noctilucent clouds above sea level was constant and equal to $H_O = 82.0$ km. The latter simplification is the cause of the primary systematic error in our method; this error can be determined by the formula (see Figure 1)

$$\Delta D = \frac{R}{R+H} \operatorname{ctg}(h+d)\,\Delta H,$$

where R is the radius of the Earth; H is the actual altitude of the cloud point,

$$\Delta H = H - H_0.$$

TABLE 1 /53

h_O \ H_{km}	75	80	85	90
5°	-38	-11	+16	+44
10	-29	-8.3	+12	+33
15	-17	-5.0	+7.5	+20

Table 1 gives the value Δ D in kilometers as a function of h and H, when H_O = 82 km.

The tables of latitudes and differences of the latitudes were calculated using the BESM-2M electronic computer of the Computer Center of the Latvian State University imeni Stuchki in 1962. The calculations are elementary, but quite numerous. Therefore it was convenient to use an electronic computer. The tables consist of 200 separate sheets - one sheet for every azimuth; on every sheet are 72 altitude values and correspondingly φ and $\Delta\lambda$, i.e., a total of 14,400 points.

The part of the table (Table 2) for the azimuth of 56° and 304° is given as an example.

The azimuth and altitude measurements on the negatives were carried out with the aid of a special transparent graph paper; this special graph pattern was designed for the AFA-IM camera (focus distance 210 mm) when the slant of the optical axis of the camera is 15°. The grid lines were drawn through every degree for the azimuth as well as for the altitude (Figure 2). At least two earth orientation points with known horizontal coordinates are required to properly orient this graph paper.

Up until the present, the projection coordinates of more than 9,000 noctilucent clouds for 1959-1961 have been determined according to the above method, including the noctilucent cloud contour of the 1961 appearances.

These results, especially if they are compared with the data of still other stations, can be further used for statistical research, for example, in the determination of the frequency of appearance of the noctilucent clouds at different latitudes.

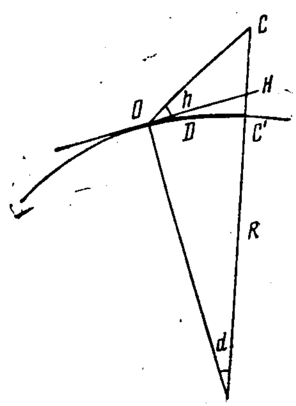

Figure 1 - Of help in the formulation of the approximate calculations formula for the processing of single photographs of the clouds.
O - observation point; C - point of a noctilucent cloud; C'- projection of point C on the earth's surface; h - apparent altitude of point C; H - altitude of point C above the earth's surface; R - Earth's radius; D - distance from the observation point to the projection point C of the noctilucent cloud; d - corresponding angular distance.

On the basis of the obtained coordinates we made some attempts to determine the velocities of the noctilucent clouds. To do this, a coordinate grid was used, which depicted in a conditional projection a sector of the earth's surface, above which the noctilucent clouds could be observed from the observation station of the Latvian Section of the All-Union Astronomical and Geodetic Society in Sigulda, i.e., from $\varphi = 57°$ to $\varphi = 63.5°$ and $\Delta\lambda = \pm 10°$ (Fig. 3). It gives practically an exact representation of the earth's surface for $\varphi = 60°$. For other latitudes, however, the grid gives a certain error in distance, which attains 0.1 km.

According to the given scale (50 mm on the originals or 31 mm on the photocopies corresponding to 1° latitude, i.e. 111 km) this error is not greater than 0.05 mm on the originals and 0.03 mm on the photocopies.

Therefore, this error is insignificant in comparison with the inaccuracy of plotting the projection points of the noctilucent clouds on the grid (more than 0.1 mm).

TABLE 2 /54

h	ϕ	$\Delta\lambda$	h	ϕ	$\Delta\lambda$
30.0°	57.830°	1.928°	5.0	59.921	9.097
29.5	57.852	1.967	4.8	59.970	9.295
29.0	57.865	2.007	4.6	60.020	9.501
28.5	57.878	2.048	4.4	60.071	9.714
28.0	57.893	2.090	4.2	60.123	9.933
27.5	57.907	2.134	4.0	60.177	10.160
27.0	57.923	2.179			

After all the known projections of all the types of noctilucent cloud objects for a number of periods of time are plotted, it is possible by means of measurements directly on the grid and by means of simple calculations to determine the velocity and direction of the movement of these objects.

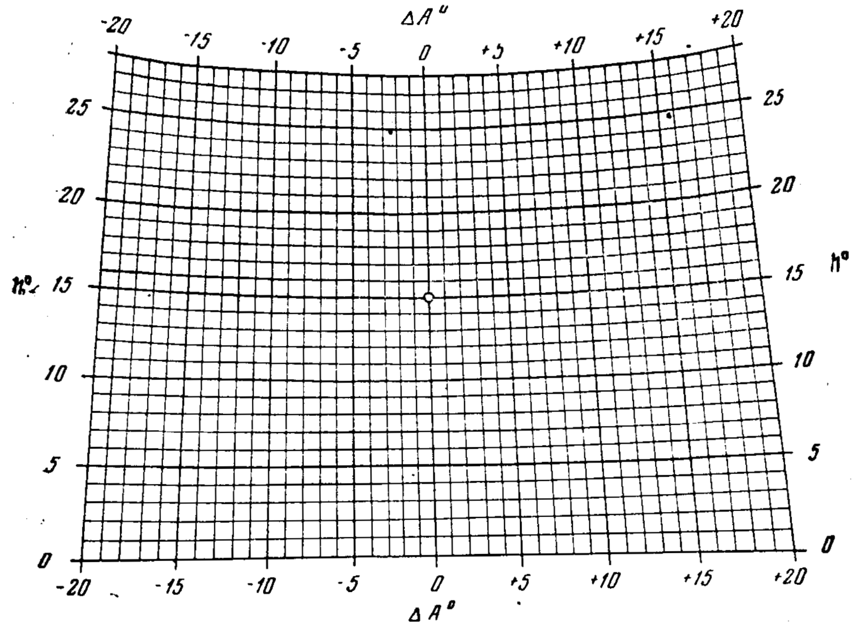

Figure 2 - Grid for the Measurement of Altitudes h and Differences of Azimuths Δ A on the Photographs When the Slope of the Optical Axis of the Camera is 15°.

The method used for determining the geographical coordinates of the noctilucent cloud projection may have the already-mentioned systematic error because of the difference between the true altitude of the noctilucent clouds and the assumed altitude H_0 = 82 km. When determining the speed and the direction of the noctilucent cloud movement, this error is not particularly significant when the noctilucent clouds do not change their altitude during the time of observation.

The most significant of the remaining errors which might occur would be the error in the determination of the apparent angular elevation of the noctilucent cloud, equal on the average to 0.1°. This error in altitude can correspond to 7 km. on the earth's surface, which is considerably greater than the error arising when using the tables to determine φ and $\Delta\lambda$ (0.5 - 1 km) and it is also considerably greater than the error in plotting the noctilucent cloud projections onto the grid ($\leqslant$ 1 km).

The movement direction (azimuth) error can vary greatly depending upon a whole series of circumstances, which in practice are difficult to express mathematically (for example, the change in the length of a strip of the II b type at one end because of a boundary displacement of the twilight segment). Nevertheless, weighing all the possible circumstances, it can be concluded that the probable error attains several degrees. /55

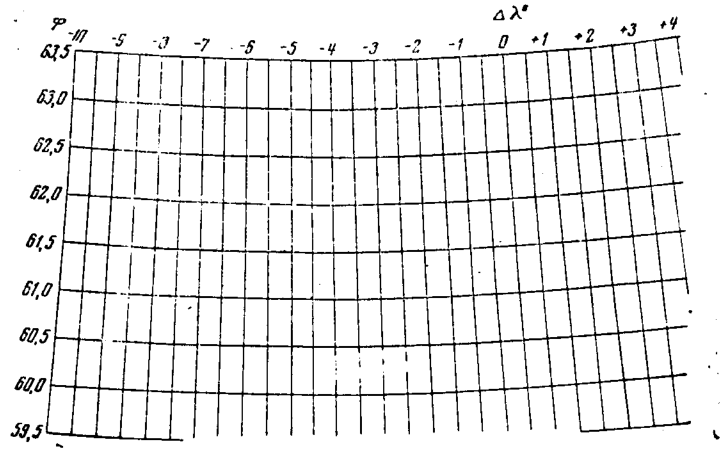

Figure 3 - Part of the coordinate grid for plotting the geographical coordinates of projections of noctilucent clouds.

Because of the fact that the apparent displacement of the noctilucent clouds is not great, part of the obtained material is not usable for practical purposes in determining velocities because the displacement of the noctilucent clouds and the error of estimation are approximately equal there (only the maximum possible velocity can be determined).

As already mentioned above, there is still another reason for the errors. This cause arises from the possible vertical displacement of the noctilucent clouds.

Actually, this error can become the most significant one. Nevertheless, it cannot be avoided in this method because we start here with the assumption of constancy of the altitude of the noctilucent clouds. To determine the exact spatial movements of the noctilucent clouds, a basic survey is needed.

For the rough estimation of values of the probable error, let us investigate three possible cases.

1. The measured formation of the noctilucent clouds moves as a whole with the vertical velocity component v_1. Consequently, in the most unfavorable case, the error Δv reaches

$$\Delta \boldsymbol{v} = v_1 \operatorname{ctg}(h + d).$$

2. In the mesopause layer and in the areas adjacent to it, a turbulent motion of the atmospheric particles takes place. As a result, different motions occur at different points of the clouds. On the average, if one takes a large number of points and studies their apparent motions for a sufficiently long time, i.e., on several photographs in a row, then the speeds obtained by our methods will show a considerable discrepancy in both the absolute values and the azimuths.

3. The observed object participates in the wave motion. Consequently, with sufficient continuity of the observations, the average velocity of the object will be close to the true one, even though velocities found for shorter time intervals may vary considerably from one another.

As an example of this process, velocities and directions for certain objects, which were photographed on July 5/6, 1959, are given in the following table. /56

TABLE 3

No.	Time (Moscow)	Object	ϕ	λ	v, m/sec	A
1	1^h12^m–1^h42^m	IV b	61°	26°	54	180°
	1 42 -1 48	IV b	61	26	54	195
2	1 42 -1 48	II b	59	24	180	174
3	1 42 -1 48	II b	60	24	166	174
4	2 04 -2 10	II b	60	26	45	200

The probable errors in v amount to ±5 m/sec., A ± 5°, not counting the error due to the probable vertical displacement of the position of certain points. The great discrepancy in the v values with relatively close values of φ and λ points to the possible presence of turbulent or wave motions in the mesopause layer. Nevertheless, analysis of the photographs used shows that within the cloud mass a definite observable flow with greater velocity existed (objects No. 2 and 3 - Table 3).

The program for the computation of the tables and computations on the BESM-2M machine was carried out by the two staff workers of the Astronomical Observatory of the Latvian State University, M.A. Dirikis and Yu.L. Frantsman. The grid (Fig. 2) was designed and drawn by S.V. Yevdokimenko.

All measurements of the negatives and determinations of the geographical coordinates according to this table were carried out by two members of the Youth Section of the Latvian Section of the All-Union Astronomical and Geodetic Society, Ye.Ye. Mukins and V.A. Berenfelds.

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